

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletbMeasurement of the ratio $\mathcal{B}(B_s^0 \rightarrow J/\psi f_0(980))/\mathcal{B}(B_s^0 \rightarrow J/\psi \phi(1020))$ in pp collisions at $\sqrt{s} = 7$ TeV

CMS Collaboration*

CERN, Switzerland

ARTICLE INFO

Article history:

Received 24 January 2015

Received in revised form 6 January 2016

Accepted 23 February 2016

Available online 27 February 2016

Editor: M. Doser

ABSTRACT

A measurement of the ratio of the branching fractions of the B_s^0 meson to $J/\psi f_0(980)$ and to $J/\psi \phi(1020)$ is presented. The J/ψ , $f_0(980)$, and $\phi(1020)$ are observed through their decays to $\mu^+\mu^-$, $\pi^+\pi^-$, and K^+K^- , respectively. The f_0 and the ϕ are identified by requiring $|M_{\pi^+\pi^-} - 974 \text{ MeV}| < 50 \text{ MeV}$ and $|M_{K^+K^-} - 1020 \text{ MeV}| < 10 \text{ MeV}$. The analysis is based on a data sample of pp collisions at a centre-of-mass energy of 7 TeV, collected by the CMS experiment at the LHC, corresponding to an integrated luminosity of 5.3 fb^{-1} . The measured ratio is $\frac{\mathcal{B}(B_s^0 \rightarrow J/\psi f_0) \mathcal{B}(f_0 \rightarrow \pi^+\pi^-)}{\mathcal{B}(B_s^0 \rightarrow J/\psi \phi) \mathcal{B}(\phi \rightarrow K^+K^-)} = 0.140 \pm 0.008 (\text{stat}) \pm 0.023 (\text{syst})$, where the first uncertainty is statistical and the second is systematic.

© 2016 CERN for the benefit of the CMS Collaboration. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>). Funded by SCOAP³.

1. Introduction

Since the observation of the decay $B_s^0 \rightarrow J/\psi \pi^+\pi^-$ with $J/\psi \rightarrow \mu^+\mu^-$, and the $\pi^+\pi^-$ mass spectrum indicating a large $f_0(980)$ component [1], this channel has been regarded with great interest in heavy-flavor physics. More detailed studies of the $\pi^+\pi^-$ mass spectrum have shown the $\pi^+\pi^-$ system to be almost entirely CP odd [2,3]. This opens up the possibility of directly measuring the lifetime of the CP-odd part of the B_s^0 meson [4,5]. In addition, the $B_s^0 \rightarrow J/\psi \pi^+\pi^-$ decay has been used for the measurement of the CP-violating phase ϕ_s [6,7], making an important contribution to the world-average value of ϕ_s [8–13]. The phase ϕ_s is predicted to be small in the standard model [14], making its determination interesting because of the large enhancements that can be introduced by new physics [15,16]. In what follows, we will refer to the $f_0(980)$ as f_0 and the $\phi(1020)$ as ϕ .

This Letter presents the measurement of the ratio $R_{f_0/\phi}$ of the branching fractions $\mathcal{B}(B_s^0 \rightarrow J/\psi f_0)\mathcal{B}(f_0 \rightarrow \pi^+\pi^-)$ and $\mathcal{B}(B_s^0 \rightarrow J/\psi \phi)\mathcal{B}(\phi \rightarrow K^+K^-)$, where in both cases the J/ψ is detected through its decay to $\mu^+\mu^-$. The f_0 and the ϕ are identified by requiring $|M_{\pi^+\pi^-} - 974 \text{ MeV}| < 50 \text{ MeV}$ and $|M_{K^+K^-} - 1020 \text{ MeV}| < 10 \text{ MeV}$. The appearance of $B_s^0 \rightarrow J/\psi f_0$ decays was first discussed in [17] with a theoretical estimate for $R_{f_0/\phi}$ of approximately 0.2, which is consistent with results from several experiments [2,4,18,19]. Detailed studies of the $\pi^+\pi^-$ mass spectrum of the $B_s^0 \rightarrow J/\psi \pi^+\pi^-$ decay in $0.3 < M_{\pi^+\pi^-} < 2.5 \text{ GeV}$ [2,3] reveal this final

state to have contributions from several resonances in $M_{\pi^+\pi^-}$, and the f_0 component to range from 65.0% to 94.5%. However, according to the same results, the contaminations from other resonances in $|M_{\pi^+\pi^-} - 974 \text{ MeV}| < 50 \text{ MeV}$ are several orders of magnitude lower than the f_0 component, including the non-resonant S-wave. Based on this, the measurement of $R_{f_0/\phi}$ is performed assuming that the selected region of $M_{\pi^+\pi^-}$ is dominated by $B_s^0 \rightarrow J/\psi f_0$ decays and neglecting other resonances. Systematic uncertainties are assigned to the measurement owing to these assumptions, taking into account the uncertainty in the f_0 component and the interferences with other resonances in the selected mass window for $M_{\pi^+\pi^-}$.

Experimentally, the ratio $R_{f_0/\phi}$ is given by

$$R_{f_0/\phi} = \frac{\mathcal{B}(B_s^0 \rightarrow J/\psi f_0) \mathcal{B}(f_0 \rightarrow \pi^+\pi^-)}{\mathcal{B}(B_s^0 \rightarrow J/\psi \phi) \mathcal{B}(\phi \rightarrow K^+K^-)} = \frac{N_{\text{obs}}^{f_0}}{N_{\text{obs}}^{\phi}} \epsilon_{\text{reco}}^{\phi/f_0}, \quad (1)$$

where $N_{\text{obs}}^{f_0}$ and N_{obs}^{ϕ} are the observed yields of $B_s^0 \rightarrow J/\psi(\mu^+\mu^-)f_0$ with $f_0 \rightarrow \pi^+\pi^-$ and $B_s^0 \rightarrow J/\psi(\mu^+\mu^-)\phi$ with $\phi \rightarrow K^+K^-$ decays, respectively, and $\epsilon_{\text{reco}}^{\phi/f_0}$ is the ratio of the detection efficiencies for the B_s^0 decay mode with a ϕ to the decay mode with a f_0 . Uncertainties in the b quark production cross section cancel in the ratio, as do those from the $J/\psi \rightarrow \mu^+\mu^-$ branching fraction and the integrated luminosity. Given the similar topologies of the two final states, systematic uncertainties related to the tracking efficiency and the muon identification also cancel in the ratio.

* E-mail address: cms-publication-committee-chair@cern.ch.

2. The CMS detector

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter. Within the 3.8 T field volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two endcap sections. Muons are measured in the pseudorapidity range $|\eta| < 2.4$ in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid, which are made using three technologies: drift tubes, cathode strip chambers, and resistive-plate chambers. Extensive forward calorimetry complements the coverage provided by the barrel and endcap detectors. The main subdetectors used in this analysis are the silicon tracker and the muon systems.

The silicon tracker measures charged particles within the pseudorapidity range $|\eta| < 2.5$ and consists of 1440 silicon pixel and 15 148 silicon strip detector modules. Matching muons to tracks measured in the silicon tracker results in a relative transverse momentum resolution for muons with $20 < p_T < 100$ GeV of 1.3–2.0% in the barrel and better than 6% in the endcaps. The p_T resolution in the barrel is better than 10% for muons with p_T up to 1 TeV [20].

The first level of the CMS trigger system, composed of custom hardware processors, uses information from the calorimeters and muon detectors to select the most interesting events in a fixed time interval of less than 4 μ s. The high-level trigger (HLT) processor farm further decreases the event rate to less than 1 kHz, before data storage.

A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [21].

3. Event selection

The data sample used for this measurement was collected in 2011 by the CMS experiment at the CERN LHC in proton–proton collisions at a centre-of-mass energy of 7 TeV and corresponds to an integrated luminosity of 5.3 fb^{-1} .

The search for $B_s^0 \rightarrow J/\psi f_0$ decays is performed in events with two muon candidates selected by the dimuon trigger at the HLT, requiring the muon pair to originate from a displaced vertex. The dimuon candidates are further required to comply with $L_{xy}/\sigma_{xy} > 3$, where L_{xy} is the magnitude of the vector \vec{L}_{xy} , which lies in a plane transverse to the beam axis and points from the interaction point to the dimuon vertex, and σ_{xy} is its uncertainty; $\cos \alpha_{J/\psi} > 0.9$, where $\alpha_{J/\psi}$ is the angle between the direction of the dimuon transverse momentum and \vec{L}_{xy} ; $p_T > 4$ GeV and $|\eta| < 2.2$ for each muon candidate; $p_T > 7$ GeV for the dimuon; the distance of closest approach of each muon track with respect to the other muon track < 0.5 cm.

Reconstruction of the $B_s^0 \rightarrow J/\psi f_0$ decays begins with the search for J/ψ candidates by combining two muons of opposite charge to form a vertex with a fit probability $> 0.5\%$ and an invariant mass ($M_{J/\psi}$) within $|M_{J/\psi} - 3097.6 \text{ MeV}| < 150 \text{ MeV}$. To search for f_0 candidates, two tracks of opposite charge assumed to be pions are constrained to a vertex with a probability $> 5\%$. One pion candidate must have $p_T > 1$ GeV and the other $p_T > 2.5$ GeV. In addition, the f_0 candidate must have $p_T > 3.5$ GeV and M_{f_0} in the range $|M_{f_0} - 974 \text{ MeV}| < 50 \text{ MeV}$. The 974 MeV is the measured mass of f_0 signal in data modeled by a Breit–Wigner function. This value is consistent with the f_0 mass from the Particle Data Group [22] and the LHCb measurement [1]. Finally, a vertex is formed with the J/ψ and f_0 candidates, constraining the dimuon mass to the nominal J/ψ mass [22]. The $B_s^0 \rightarrow J/\psi f_0$ candidates are required to have a vertex probability $> 10\%$, $p_T > 13$ GeV, $\cos \alpha_{B_s^0} > 0.994$,

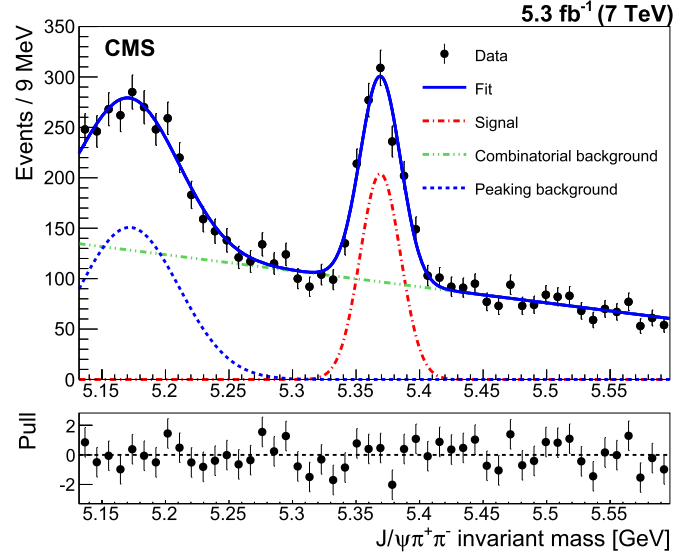


Fig. 1. Invariant mass distribution of the $B_s^0 \rightarrow J/\psi(\mu^+\mu^-)f_0(\pi^+\pi^-)$ candidates (filled circles). The signal is modeled as a Gaussian (dot-dashed line), the combinatorial background as a first-order polynomial function (dashed-double-dotted line), and the peaking background by a Gaussian (dotted line). The result of the total fit is shown with the solid line. The bottom plot shows the pull, which is the deviation of the data from the fit divided by the uncertainty in the data.

where $\alpha_{B_s^0}$ is the angle between the direction of the B_s^0 transverse momentum and the vector \vec{L}_{xy} , and a proper decay length $> 100 \mu\text{m}$. The proper decay length is defined as $(\vec{L}_{xy} \cdot \vec{p}_T) M_B / p_T^2$, where \vec{p}_T is the transverse momentum of the B_s^0 candidate and M_B is the world-average B_s^0 mass [22]. In the case of multiple B_s^0 candidates per event, the one with smallest B_s^0 vertex fit χ^2 is selected. The selection criteria for the B_s^0 candidates are established by maximizing $S/\sqrt{S+B}$, where S is the signal yield obtained from Monte Carlo (MC) simulation and B is the background yield taken from sideband regions, defined as the number of events with a $\mu^+\mu^-\pi^+\pi^-$ invariant mass in the range 5.27 to 5.30 GeV or 5.43 to 5.46 GeV.

The same procedure and selection criteria are applied to the reconstruction of the normalization channel $B_s^0 \rightarrow J/\psi \phi$, except that the invariant mass requirement $|M_\phi - 1020 \text{ MeV}| < 10 \text{ MeV}$ is tighter than that for the f_0 .

4. Results

The signal yields of both decay channels are extracted using unbinned maximum-likelihood fits of the mass distributions. The invariant mass distribution of the $J/\psi(\mu^+\mu^-)f_0(\pi^+\pi^-)$ candidates is shown in Fig. 1. It is fit with a superposition of a Gaussian function representing the signal, a polynomial function to account for the combinatorial background, and another Gaussian function for any possible peaking background. The latter models resonant structures that could appear in the left sideband of the $J/\psi(\mu^+\mu^-)f_0(\pi^+\pi^-)$ signal mass owing to the misidentification of a kaon as a pion coming from decays such as $B^0 \rightarrow J/\psi K^*(892)(K^+\pi^-)$ and $B_s^0 \rightarrow J/\psi K^+K^-$, as examples. In addition, $B^+ \rightarrow J/\psi K^+(\pi^+)$ decays can be a source of background when combined with an extra background pion candidate. When allowing all parameters to float, the fit returns $N_{\text{obs}}^{f_0} = 873 \pm 49$ events and a B_s^0 mass of $5369.1 \pm 0.9 \text{ MeV}$, with a resolution of $15.9 \pm 0.9 \text{ MeV}$, where the uncertainties are statistical only. The measured values of the B_s^0 mass and its resolution are consistent with the MC simulation.

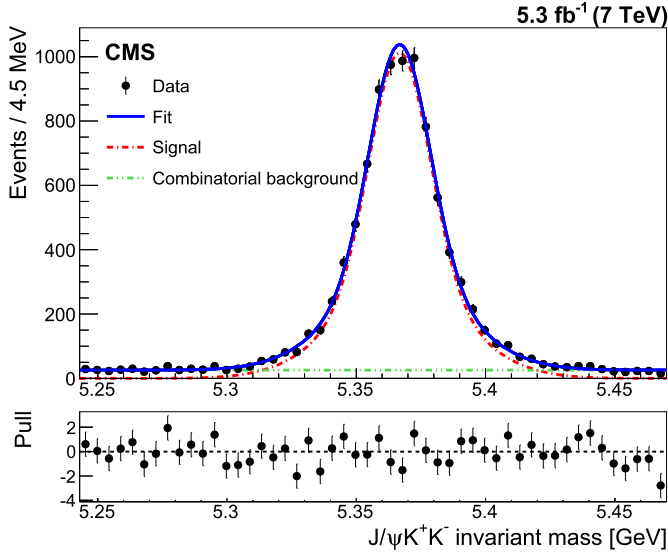


Fig. 2. Invariant mass distribution of the $B_s^0 \rightarrow J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ candidates (black filled circles). The signal model is a double Gaussian (dot-dashed line), while the combinatorial background model is a constant function (dash-double-dotted line). The total fit is represented by the solid line. The bottom plot shows the deviation of the data to the fit divided by the statistical uncertainty in the data.

The $J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ invariant mass distribution is modeled by two Gaussian functions for the signal and a constant function for the combinatorial background. A signal yield of $N_{\text{obs}}^\phi = 8377 \pm 107$ events is obtained, with a B_s^0 mass of 5366.8 ± 0.2 MeV and a resolution of 17.1 ± 0.1 MeV, which are consistent with the MC simulation. The corresponding invariant mass distribution is presented in Fig. 2.

Using the MC simulation, the detection efficiencies for the two processes are calculated as the ratio of the reconstructed and generated yields. The B_s^0 meson production is simulated using PYTHIA 6.4.24 [23] and its decays simulated with EVTGEN [24]. The B_s^0 mass and lifetime are set to 5369.6 MeV and 438 μm in the simulation. The decay model used for the $B_s^0 \rightarrow J/\psi f_0$ decay is a phase-space model reweighted to reflect the spin-1 structure of the $J/\psi \rightarrow \mu^+\mu^-$ decay. The corresponding models for the $B_s^0 \rightarrow J/\psi\phi$ decay are: a pseudoscalar–vector–vector with CP violation [25,26] for the B_s^0 decay, with parameters [24] $\|A_{\parallel}\|^2 = 0.24$, $\|A_0\|^2 = 0.6$, $\|A_{\perp}\|^2 = 0.16$, $\phi_{\parallel} = 2.5$, $\phi_0 = 0$, and $\phi_{\perp} = -0.17$; a vector–lepton–lepton model with radiation (PHOTOS) [27] for the $J/\psi \rightarrow \mu^+\mu^-$ decay; and a vector–scalar–scalar model [24] for the $\phi \rightarrow K^+K^-$ decay. The events are processed with a GEANT4-based detector simulation [28] and the same reconstruction algorithms used on data. In order to validate the MC simulation samples, relevant kinematic and geometric variables of both simulated decay channels are compared with the data after background subtraction and found to be in agreement. For example, Fig. 3 compares the p_T and invariant mass distributions of the $f_0(\pi^+\pi^-)$ candidates for background-subtracted data and MC simulation. The f_0 width was set to 50 MeV in the MC simulation. This is consistent with what is observed in our data as shown in the Fig. 3.b. The ratio of the detection efficiencies for the two B_s^0 decays is calculated to be $\epsilon_{f_0}^{\phi/f_0} = 1.344 \pm 0.095$, where the uncertainty reflects the limited size of simulated samples. Using the corresponding values of $N_{\text{obs}}^{f_0}$, N_{obs}^{ϕ} , and $\epsilon_{\text{reco}}^{\phi/f_0}$ in Eq. (1), we measure $R_{f_0/\phi} = 0.140 \pm 0.008$, where the uncertainty is statistical only.

The stability of the $R_{f_0/\phi}$ measurement is verified with control checks using different run periods, selection criteria, and geometric acceptances. To study possible effects from varying run conditions,

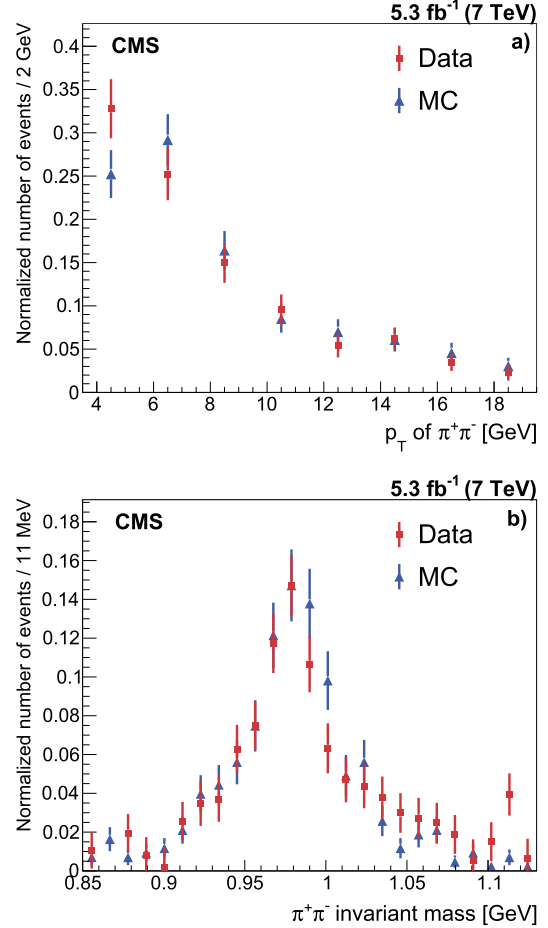


Fig. 3. Comparison of normalized MC simulation (triangles) and background-subtracted data (squares) for (a) the p_T and (b) invariant mass distributions of the $f_0(\pi^+\pi^-)$ candidates.

the value of $R_{f_0/\phi}$ is determined for two subsamples, found by dividing the data into two. The ratio is also measured after changing the selection criteria for the proper decay length and p_T of the B_s^0 candidates and the p_T of the leading and subleading pion candidates, and by using different azimuthal angle and η requirements for the muons. None of these cross-checks revealed any statistically significant bias.

5. Systematic uncertainties

Potential systematic uncertainties in the measurement of $R_{f_0/\phi}$ come from sources such as the B_s^0 signal yield extraction procedure, the relative efficiency estimation, and possible contributions to the B_s^0 yields from other decays producing the $J/\psi\pi^+\pi^-$ and $J/\psi K^+K^-$ final states.

Systematic uncertainties in the signal yield extraction are estimated by changing the modeling of the signal and the background invariant mass distributions in the likelihood fits. For the case of the $B_s^0 \rightarrow J/\psi f_0$ mass distribution the signal shape is changed to a double-Gaussian function and the background to an exponential function, while for the $B_s^0 \rightarrow J/\psi\phi$ mass distribution the signal is changed to a Gaussian function and its background is modeled as a first-order polynomial function. These changes lead to a maximum variation of 2.1% in $R_{f_0/\phi}$.

There are several factors that may affect the estimate of $\epsilon_{\text{reco}}^{\phi/f_0}$. While the MC simulation package uses a Breit–Wigner model to simulate the $f_0 \rightarrow \pi^+\pi^-$ process, it has been pointed out [2,3]

that a Flatté model is a better description of this decay. To estimate the effect of the simulation model, the Breit–Wigner model used in the simulation is compared to a Flatté model in the selected $M_{\pi^+\pi^-}$ region. The difference in the models reflects a systematic error of 5.8% in $\epsilon_{\text{reco}}^{\phi/f_0}$. This is quoted as a systematic uncertainty. In addition, in the MC simulation the f_0 width is set to 50 MeV. This value is varied by ± 10 MeV, resulting in a systematic uncertainty of 8.6% in $R_{f_0/\phi}$. The models used in the MC simulation of the B_s decays are set to phase-space [24] instead of the default decay models, leading to a 6.2% systematic uncertainty in $R_{f_0/\phi}$. Finally, the statistical uncertainty in $\epsilon_{\text{reco}}^{\phi/f_0}$ owing to the finite number of MC events, which corresponds to 7.1%, is added as a systematic uncertainty.

As mentioned in the introduction, detailed studies of the $\pi^+\pi^-$ mass spectrum of the $B_s^0 \rightarrow J/\psi \pi^+\pi^-$ decay [2,3] in a mass window of 0.3–2.5 GeV, reveal this final state to have contributions from several resonances in $M_{\pi^+\pi^-}$, and the f_0 component to range from 65.0 to 94.5% in the entire mass window studied by LHCb. To study the effects of the interferences and the f_0 fraction observed by LHCb in the estimate of $\epsilon_{\text{reco}}^{\phi/f_0}$, the model reported in [3] for the lowest f_0 fraction and largest non-resonant component was compared to the single Breit–Wigner model used in the MC simulation of the $f_0 \rightarrow \pi^+\pi^-$ decay. The comparison in the selected $M_{\pi^+\pi^-}$ region shows a variation of 5.6% in $R_{f_0/\phi}$. This is quoted as a systematic uncertainty coming from this source. It can be observed in the same LHCb study that the contaminations from other resonances in the mass region $|M_{\pi^+\pi^-} - 974 \text{ MeV}| < 50 \text{ MeV}$ are several orders of magnitude lower than the f_0 component, including the non-resonant S-wave. To estimate the variation in the B_s^0 yield coming from these possible contributions, the f_0 mass window is widened from 50 to 100 MeV around the f_0 mass, resulting in a variation in $R_{f_0/\phi}$ of 6.4% that is quoted as a systematic uncertainty. For the $B_s^0 \rightarrow J/\psi K^+K^-$ decay channel, the contribution of the S-wave in a ϕ mass window similar to what is used in this analysis has been found to be negligible [29].

Combining these uncertainties in quadrature leads to a total systematic uncertainty of 16.5%.

6. Summary

Using data collected by the CMS experiment in proton–proton collisions at $\sqrt{s} = 7 \text{ TeV}$, corresponding to an integrated luminosity of 5.3 fb^{-1} , 873 ± 49 events of $B_s^0 \rightarrow J/\psi(\mu^+\mu^-)f_0(\pi^+\pi^-)$ and 8377 ± 107 events of $B_s^0 \rightarrow J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ are observed. The f_0 and ϕ are identified in the mass ranges $|M_{\pi^+\pi^-} - 974 \text{ MeV}| < 50 \text{ MeV}$ and $|M_{K^+K^-} - 1020 \text{ MeV}| < 10 \text{ MeV}$, respectively. The ratio of the branching fraction of $B_s^0 \rightarrow J/\psi(\mu^+\mu^-)f_0(\pi^+\pi^-)$ to the branching fraction of $B_s^0 \rightarrow J/\psi(\mu^+\mu^-)\phi(K^+K^-)$, $R_{f_0/\phi}$, is found to be

$$\frac{\mathcal{B}(B_s^0 \rightarrow J/\psi f_0) \mathcal{B}(f_0 \rightarrow \pi^+\pi^-)}{\mathcal{B}(B_s^0 \rightarrow J/\psi \phi) \mathcal{B}(\phi \rightarrow K^+K^-)} = 0.140 \pm 0.008 (\text{stat}) \pm 0.023 (\text{syst}). \quad (2)$$

This result is consistent with the theoretical prediction of about 0.2 [17] and with previous measurements in different ranges of $M_{\pi^+\pi^-}$ [2,4,19].

Acknowledgements

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centres and

personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWFW and FWF (Austria); Fonds De La Recherche Scientifique – FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES and CSF (Croatia); RPF (Cyprus); MoER, ERC IUT and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); LAS (Lithuania); MOE and UM (Malaysia); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS and RFBR (Russia); MESTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU and SFFR (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

Individuals have received support from the Marie-Curie programme and the European Research Council and EPLANET (European Union); the Leventis Foundation; the A.P. Sloan Foundation; the Alexander von Humboldt Foundation; the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; the Council of Science and Industrial Research, India; the HOMING PLUS programme of Foundation for Polish Science, cofinanced from European Union, Regional Development Fund; the Compagnia di San Paolo (Torino); the Consorzio per la Fisica (Trieste); MIUR project 20108T4XTM (Italy); the Thalís and Aristeia programmes cofinanced by EU-ESF and the Greek NSRF; and the National Priorities Research Program by Qatar National Research Fund.

References

- [1] LHCb Collaboration, First observation of $B_s^0 \rightarrow J/\psi f_0(980)$ decays, Phys. Lett. B 698 (2011) 115, <http://dx.doi.org/10.1016/j.physletb.2011.03.006>, arXiv:1102.0206.
- [2] LHCb Collaboration, Analysis of the resonant components in $\bar{B}_s^0 \rightarrow J/\psi \pi^+\pi^-$, Phys. Rev. D 86 (2012) 052006, <http://dx.doi.org/10.1103/PhysRevD.86.052006>, arXiv:1204.5643.
- [3] LHCb Collaboration, Measurement of the resonant and CP components in $\bar{B}_s^0 \rightarrow J/\psi \pi^+\pi^-$ decays, Phys. Rev. D 89 (2014) 092006, <http://dx.doi.org/10.1103/PhysRevD.89.092006>, arXiv:1402.6248.
- [4] CDF Collaboration, T. Aaltonen, et al., Measurement of branching ratio and B_s^0 lifetime in the decay $B_s^0 \rightarrow J/\psi f_0(980)$ at CDF, Phys. Rev. D 84 (2011) 052012, <http://dx.doi.org/10.1103/PhysRevD.84.052012>, arXiv:1106.3682.
- [5] LHCb Collaboration, Measurement of the B_s^0 effective lifetime in the $J/\psi f_0(980)$ final state, Phys. Rev. Lett. 109 (2012) 152002, <http://dx.doi.org/10.1103/PhysRevLett.109.152002>, arXiv:1207.0878.
- [6] LHCb Collaboration, Measurement of the CP-violating phase ϕ_s in $\bar{B}_s^0 \rightarrow J/\psi f_0(980)$, Phys. Lett. B 707 (2012) 497, <http://dx.doi.org/10.1016/j.physletb.2012.01.017>, arXiv:1112.3056.
- [7] LHCb Collaboration, Measurement of the CP-violating phase ϕ_s in $\bar{B}_s^0 \rightarrow J/\psi \pi^+\pi^-$ decays, Phys. Lett. B 736 (2014) 186, <http://dx.doi.org/10.1016/j.physletb.2014.06.079>, arXiv:1405.4140.
- [8] D0 Collaboration, V.M. Abazov, et al., Measurement of B_s^0 mixing parameters from the flavor-tagged decay $B_s^0 \rightarrow J/\psi \phi$, Phys. Rev. Lett. 101 (2008) 241801, <http://dx.doi.org/10.1103/PhysRevLett.101.241801>, arXiv:0802.2255.
- [9] CDF Collaboration, T. Aaltonen, et al., First flavor-tagged determination of bounds on mixing-induced CP violation in $B_s^0 \rightarrow J/\psi \phi$ decays, Phys. Rev. Lett. 100 (2008) 161802, <http://dx.doi.org/10.1103/PhysRevLett.100.161802>, arXiv:0712.2397.
- [10] D0 Collaboration, V.M. Abazov, et al., Measurement of the CP-violating phase $\phi_s^{J/\psi \phi}$ using the flavor-tagged decay $B_s^0 \rightarrow J/\psi \phi$ in 8 fb $^{-1}$ of $p\bar{p}$ collisions,

- Phys. Rev. D 85 (2012) 032006, <http://dx.doi.org/10.1103/PhysRevD.85.032006>, arXiv:1109.3166.
- [11] LHCb Collaboration, Measurement of the CP-violating phase ϕ_s in the decay $B_s^0 \rightarrow J/\psi \phi$, Phys. Rev. Lett. 108 (2012) 101803, <http://dx.doi.org/10.1103/PhysRevLett.108.101803>, arXiv:1112.3183.
- [12] ATLAS Collaboration, Time-dependent angular analysis of the decay $B_s^0 \rightarrow J/\psi \phi$ and extraction of $\Delta\Gamma_s$ and the CP-violating weak phase ϕ_s by ATLAS, J. High Energy Phys. 12 (2012) 072, [http://dx.doi.org/10.1007/JHEP12\(2012\)072](http://dx.doi.org/10.1007/JHEP12(2012)072), arXiv:1208.0572.
- [13] CMS Collaboration, Measurement of the CP-violating weak phase ϕ_s and the decay width difference $\Delta\Gamma_s$ using the $B_s^0 \rightarrow J/\psi \phi$ (1020) decay channel in pp collisions at $\sqrt{s} = 8$ TeV, Phys. Lett. B (2015), arXiv:1507.07527, submitted for publication.
- [14] J. Charles, O. Deschamps, S. Descotes-Genon, R. Itoh, H. Lacker, A. Menzel, S. Monteil, V. Niess, J. Ocariz, J. Orloff, S. T'Jampens, V. Tisserand, K. Trabelsi, Predictions of selected flavour observables within the standard model, Phys. Rev. D 84 (2011) 033005, <http://dx.doi.org/10.1103/PhysRevD.84.033005>, arXiv:1106.4041.
- [15] P. Ball, R. Fleischer, Probing new physics through B mixing: status, benchmarks and prospects, Eur. Phys. J. C 48 (2006) 413, <http://dx.doi.org/10.1140/epjc/s10052-006-0034-4>, arXiv:hep-ph/0604249.
- [16] A. Lenz, Unparticle physics effects in B_s – \bar{B}_s mixing, Phys. Rev. D 76 (2007) 065006, <http://dx.doi.org/10.1103/PhysRevD.76.065006>, arXiv:0707.1535.
- [17] S. Stone, L. Zhang, S-waves and the measurement of CP-violating phases in B_s decays, Phys. Rev. D 79 (2009) 074024, <http://dx.doi.org/10.1103/PhysRevD.79.074024>, arXiv:0812.2832.
- [18] BELLE Collaboration, J. Li, et al., Observation of $B_s^0 \rightarrow J/\psi f_0(980)$ and evidence for $B_s^0 \rightarrow J/\psi f_0(1370)$, Phys. Rev. Lett. 106 (2011) 121802, <http://dx.doi.org/10.1103/PhysRevLett.106.121802>, arXiv:1102.2759.
- [19] D0 Collaboration, V.M. Abazov, et al., Measurement of the relative branching ratio of $B_s^0 \rightarrow J/\psi f_0(980)$ to $B_s^0 \rightarrow J/\psi \phi$, Phys. Rev. D 85 (2012) 011103, <http://dx.doi.org/10.1103/PhysRevD.85.011103>, arXiv:1110.4272.
- [20] CMS Collaboration, Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV, J. Instrum. 7 (2012) P10002, <http://dx.doi.org/10.1088/1748-0221/7/10/P10002>, arXiv:1206.4071.
- [21] CMS Collaboration, The CMS experiment at the CERN LHC, J. Instrum. 03 (2008) S08004, <http://dx.doi.org/10.1088/1748-0221/3/08/S08004>.
- [22] Particle Data Group, J. Beringer, et al., Review of particle physics, Phys. Rev. D 86 (2012) 010001, <http://dx.doi.org/10.1103/PhysRevD.86.010001>.
- [23] T. Sjöstrand, S. Mrenna, P. Skands, PYTHIA 6.4 physics and manual, J. High Energy Phys. 05 (2006) 026, <http://dx.doi.org/10.1088/1126-6708/2006/05/026>, arXiv:hep-ph/0603175.
- [24] D. Lange, The EvtGen particle decay simulation package, Nucl. Instrum. Methods A 462 (2001) 152, [http://dx.doi.org/10.1016/S0168-9002\(01\)00089-4](http://dx.doi.org/10.1016/S0168-9002(01)00089-4).
- [25] I. Dunietz, H. Quinn, A. Snyder, W. Toki, H.J. Lipkin, How to extract CP-violating asymmetries from angular correlations, Phys. Rev. D 43 (1991) 2193, <http://dx.doi.org/10.1103/PhysRevD.43.2193>.
- [26] BaBar Collaboration, B. Aubert, et al., Measurement of the $B \rightarrow J/\psi K^*(892)$ decay amplitudes, Phys. Rev. Lett. 87 (2001) 241801, <http://dx.doi.org/10.1103/PhysRevLett.87.241801>, hep-ex/0107049.
- [27] P. Golonka, Z. Was, PHOTOS Monte Carlo: a precision tool for QED corrections in Z and W decays, Eur. Phys. J. C 45 (2006) 97, <http://dx.doi.org/10.1140/epjc/s2005-02396-4>, arXiv:hep-ph/0506026.
- [28] GEANT4 Collaboration, S. Agostinelli, et al., Geant4—a simulation toolkit, Nucl. Instrum. Methods A 506 (2003) 250, [http://dx.doi.org/10.1016/S0168-9002\(03\)01368-8](http://dx.doi.org/10.1016/S0168-9002(03)01368-8).
- [29] CDF Collaboration, T. Aaltonen, et al., Measurement of the bottom-strange meson mixing phase in the full CDF data set, Phys. Rev. Lett. 109 (2012) 171802, <http://dx.doi.org/10.1103/PhysRevLett.109.171802>, arXiv:1208.2967.

CMS Collaboration

V. Khachatryan, A.M. Sirunyan, A. Tumasyan

Yerevan Physics Institute, Yerevan, Armenia

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, M. Friedl, R. Frühwirth¹, V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler¹, W. Kiesenhofer, V. Knünz, M. Krammer¹, I. Krätschmer, D. Liko, I. Mikulec, D. Rabady², B. Rahbaran, H. Rohringer, R. Schöfbeck, J. Strauss, W. Treberer-Treberspur, W. Waltenberger, C.-E. Wulz¹

Institut für Hochenergiephysik der OeAW, Wien, Austria

V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

National Centre for Particle and High Energy Physics, Minsk, Belarus

S. Alderweireldt, S. Bansal, T. Cornelis, E.A. De Wolf, X. Janssen, A. Knutsson, J. Lauwers, S. Luyckx, S. Ochesanu, R. Rougny, M. Van De Klundert, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Universiteit Antwerpen, Antwerpen, Belgium

F. Blekman, S. Blyweert, J. D'Hondt, N. Daci, N. Heracleous, J. Keaveney, S. Lowette, M. Maes, A. Olbrechts, Q. Python, D. Strom, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Villella

Vrije Universiteit Brussel, Brussel, Belgium

C. Caillol, B. Clerbaux, G. De Lentdecker, D. Dobur, L. Favart, A.P.R. Gay, A. Grebenyuk, A. Léonard, A. Mohammadi, L. Perniè², A. Randle-conde, T. Reis, T. Seva, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wang, F. Zenoni

Université Libre de Bruxelles, Bruxelles, Belgium

V. Adler, K. Beernaert, L. Benucci, A. Cimmino, S. Costantini, S. Crucy, A. Fagot, G. Garcia, J. McCartin, A.A. Ocampo Rios, D. Poyraz, D. Ryckbosch, S. Salva Diblen, M. Sigamani, N. Strobbe, F. Thyssen, M. Tytgat, E. Yazgan, N. Zaganidis

Ghent University, Ghent, Belgium

S. Basegmez, C. Beluffi³, G. Bruno, R. Castello, A. Caudron, L. Ceard, G.G. Da Silva, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco⁴, J. Hollar, A. Jafari, P. Jez, M. Komm, V. Lemaitre, C. Nuttons, D. Pagano, L. Perrini, A. Pin, K. Piotrkowski, A. Popov⁵, L. Quertenmont, M. Selvaggi, M. Vidal Marono, J.M. Vizan Garcia

Université Catholique de Louvain, Louvain-la-Neuve, Belgium

N. Beliy, T. Caebergs, E. Daubie, G.H. Hammad

Université de Mons, Mons, Belgium

W.L. Aldá Júnior, G.A. Alves, L. Brito, M. Correa Martins Junior, T. Dos Reis Martins, J. Molina, C. Mora Herrera, M.E. Pol, P. Rebello Teles

Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil

W. Carvalho, J. Chinellato⁶, A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, H. Malbouisson, D. Matos Figueiredo, L. Mundim, H. Nogima, W.L. Prado Da Silva, J. Santaolalla, A. Santoro, A. Sznajder, E.J. Tonelli Manganote⁶, A. Vilela Pereira

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

C.A. Bernardes^b, S. Dogra^a, T.R. Fernandez Perez Tomei^a, E.M. Gregores^b, P.G. Mercadante^b, S.F. Novaes^a, Sandra S. Padula^a

^a *Universidade Estadual Paulista, São Paulo, Brazil*

^b *Universidade Federal do ABC, São Paulo, Brazil*

A. Aleksandrov, V. Genchev², R. Hadjiiska, P. Iaydjiev, A. Marinov, S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, M. Vutova

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

A. Dimitrov, I. Glushkov, L. Litov, B. Pavlov, P. Petkov

University of Sofia, Sofia, Bulgaria

J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, T. Cheng, R. Du, C.H. Jiang, R. Plestina⁷, F. Romeo, J. Tao, Z. Wang

Institute of High Energy Physics, Beijing, China

C. Asawatangtrakuldee, Y. Ban, S. Liu, Y. Mao, S.J. Qian, D. Wang, Z. Xu, L. Zhang, W. Zou

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

C. Avila, A. Cabrera, L.F. Chaparro Sierra, C. Florez, J.P. Gomez, B. Gomez Moreno, J.C. Sanabria

Universidad de Los Andes, Bogota, Colombia

N. Godinovic, D. Lelas, D. Polic, I. Puljak

University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia

Z. Antunovic, M. Kovac

University of Split, Faculty of Science, Split, Croatia

V. Brigljevic, K. Kadija, J. Luetic, D. Mekterovic, L. Sudic

Institute Rudjer Boskovic, Zagreb, Croatia

A. Attikis, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis, H. Rykaczewski

University of Cyprus, Nicosia, Cyprus

M. Bodlak, M. Finger, M. Finger Jr.⁸

Charles University, Prague, Czech Republic

Y. Assran⁹, A. Ellithi Kamel¹⁰, M.A. Mahmoud¹¹, A. Radi^{12,13}

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt

M. Kadastik, M. Murumaa, M. Raidal, A. Tiko

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

P. Eerola, M. Voutilainen

Department of Physics, University of Helsinki, Helsinki, Finland

J. Härkönen, V. Karimäki, R. Kinnunen, M.J. Kortelainen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, L. Wendland

Helsinki Institute of Physics, Helsinki, Finland

J. Talvitie, T. Tuuva

Lappeenranta University of Technology, Lappeenranta, Finland

M. Besancon, F. Couderc, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, C. Favaro, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, J. Rander, A. Rosowsky, M. Titov

DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France

S. Baffioni, F. Beaudette, P. Busson, E. Chapon, C. Charlot, T. Dahms, M. Dalchenko, L. Dobrzynski, N. Filipovic, A. Florent, R. Granier de Cassagnac, L. Mastrolorenzo, P. Miné, I.N. Naranjo, M. Nguyen, C. Ochando, G. Ortona, P. Paganini, S. Regnard, R. Salerno, J.B. Sauvan, Y. Sirois, C. Veelken, Y. Yilmaz, A. Zabi

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France

J.-L. Agram¹⁴, J. Andrea, A. Aubin, D. Bloch, J.-M. Brom, E.C. Chabert, C. Collard, E. Conte¹⁴, J.-C. Fontaine¹⁴, D. Gelé, U. Goerlach, C. Goetzmann, A.-C. Le Bihan, K. Skovpen, P. Van Hove

Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France

S. Gadrat

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France

S. Beauceron, N. Beaupere, C. Bernet⁷, G. Boudoul², E. Bouvier, S. Brochet, C.A. Carrillo Montoya, J. Chasserat, R. Chierici, D. Contardo², B. Courbon, P. Depasse, H. El Mamouni, J. Fan, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, A.L. Pequegnot, S. Perries, J.D. Ruiz Alvarez, D. Sabes, L. Sgandurra, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret, H. Xiao

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France

Z. Tsamalaidze⁸

Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia

C. Autermann, S. Beranek, M. Bontenackels, M. Edelhoff, L. Feld, A. Heister, K. Klein, M. Lipinski, A. Ostapchuk, M. Preuten, F. Raupach, J. Sammet, S. Schael, J.F. Schulte, H. Weber, B. Wittmer, V. Zhukov⁵

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany

M. Ata, M. Brodski, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, S. Knutzen, P. Kreuzer, M. Merschmeyer, A. Meyer, P. Millet, M. Olschewski, K. Padeken, P. Papacz, H. Reithler, S.A. Schmitz, L. Sonnenschein, D. Teyssier, S. Thüer

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany

V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Künsken, J. Lingemann², A. Nowack, I.M. Nugent, C. Pistone, O. Pooth, A. Stahl

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany

M. Aldaya Martin, I. Asin, N. Bartosik, J. Behr, U. Behrens, A.J. Bell, A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, S. Choudhury, F. Costanza, C. Diez Pardos, G. Dolinska, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, J. Garay Garcia, A. Geiser, A. Gizhko, P. Gunnellini, J. Hauk, M. Hempel¹⁵, H. Jung, A. Kalogeropoulos, O. Karacheban¹⁵, M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, I. Korol, D. Krücker, W. Lange, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann¹⁵, B. Lutz, R. Mankel, I. Marfin¹⁵, I.-A. Melzer-Pellmann, A.B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, S. Naumann-Emme, A. Nayak, E. Ntomari, H. Perrey, D. Pitzl, R. Placakyte, A. Raspereza, P.M. Ribeiro Cipriano, B. Roland, E. Ron, M.Ö. Sahin, J. Salfeld-Nebgen, P. Saxena, T. Schoerner-Sadenius, M. Schröder, C. Seitz, S. Spannagel, A.D.R. Vargas Trevino, R. Walsh, C. Wissing

Deutsches Elektronen-Synchrotron, Hamburg, Germany

V. Blobel, M. Centis Vignali, A.R. Draeger, J. Erfle, E. Garutti, K. Goebel, M. Görner, J. Haller, M. Hoffmann, R.S. Höing, A. Junkes, H. Kirschenmann, R. Klanner, R. Kogler, T. Lapsien, T. Lenz, I. Marchesini, D. Marconi, J. Ott, T. Peiffer, A. Perieanu, N. Pietsch, J. Poehlsen, T. Poehlsen, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Seidel, V. Sola, H. Stadie, G. Steinbrück, D. Troendle, E. Usai, L. Vanelderen, A. Vanhoefer

University of Hamburg, Hamburg, Germany

C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, F. Frensch, M. Giffels, A. Gilbert, F. Hartmann², T. Hauth, U. Husemann, I. Katkov⁵, A. Kornmayer², P. Lobelle Pardo, M.U. Mozer, T. Müller, Th. Müller, A. Nürnberg, G. Quast, K. Rabbertz, S. Röcker, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, R. Wolf

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

G. Anagnostou, G. Daskalakis, T. Gerasis, V.A. Giakoumopoulou, A. Kyriakis, D. Loukas, A. Markou, C. Markou, A. Psallidas, I. Topsis-Giotis

Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece

A. Agapitos, S. Kesisoglou, A. Panagiotou, N. Saoulidou, E. Stiliaris, E. Tziaferi

University of Athens, Athens, Greece

X. Aslanoglou, I. Evangelou, G. Flouris, C. Foudas, P. Kokkas, N. Manthos, I. Papadopoulos, E. Paradas, J. Strologas

University of Ioánnina, Ioánnina, Greece

G. Bencze, C. Hajdu, P. Hidas, D. Horvath¹⁶, F. Sikler, V. Veszpremi, G. Vesztergombi¹⁷, A.J. Zsigmond

Wigner Research Centre for Physics, Budapest, Hungary

N. Beni, S. Czellar, J. Karancsi¹⁸, J. Molnar, J. Palinkas, Z. Szillasi

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

A. Makovec, P. Raics, Z.L. Trocsanyi, B. Ujvari

University of Debrecen, Debrecen, Hungary

S.K. Swain

National Institute of Science Education and Research, Bhubaneswar, India

S.B. Beri, V. Bhatnagar, R. Gupta, U. Bhawandeep, A.K. Kalsi, M. Kaur, R. Kumar, M. Mittal, N. Nishu, J.B. Singh

Panjab University, Chandigarh, India

Ashok Kumar, Arun Kumar, S. Ahuja, A. Bhardwaj, B.C. Choudhary, A. Kumar, S. Malhotra, M. Naimuddin, K. Ranjan, V. Sharma

University of Delhi, Delhi, India

S. Banerjee, S. Bhattacharya, K. Chatterjee, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, A. Modak, S. Mukherjee, D. Roy, S. Sarkar, M. Sharan

Saha Institute of Nuclear Physics, Kolkata, India

A. Abdulsalam, D. Dutta, V. Kumar, A.K. Mohanty², L.M. Pant, P. Shukla, A. Topkar

Bhabha Atomic Research Centre, Mumbai, India

T. Aziz, S. Banerjee, S. Bhowmik¹⁹, R.M. Chatterjee, R.K. Dewanjee, S. Dugad, S. Ganguly, S. Ghosh, M. Guchait, A. Gurtu²⁰, G. Kole, S. Kumar, M. Maity¹⁹, G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage²¹

Tata Institute of Fundamental Research, Mumbai, India

S. Sharma

Indian Institute of Science Education and Research (IISER), Pune, India

H. Bakhshiansohi, H. Behnamian, S.M. Etesami²², A. Fahim²³, R. Goldouzian, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi, F. Rezaei Hosseinabadi, B. Safarzadeh²⁴, M. Zeinali

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran

M. Felcini, M. Grunewald

University College Dublin, Dublin, Ireland

M. Abbrescia^{a,b}, C. Calabria^{a,b}, S.S. Chhibra^{a,b}, A. Colaleo^a, D. Creanza^{a,c}, L. Cristella^{a,b}, N. De Filippis^{a,c}, M. De Palma^{a,b}, L. Fiore^a, G. Iaselli^{a,c}, G. Maggi^{a,c}, M. Maggi^a, S. My^{a,c}, S. Nuzzo^{a,b}, A. Pompili^{a,b}, G. Pugliese^{a,c}, R. Radogna^{a,b,2}, G. Selvaggi^{a,b}, A. Sharma^a, L. Silvestris^{a,2}, R. Venditti^{a,b}, P. Verwilligen^a

^a INFN Sezione di Bari, Bari, Italy

^b Università di Bari, Bari, Italy

^c Politecnico di Bari, Bari, Italy

G. Abbiendi^a, A.C. Benvenuti^a, D. Bonacorsi^{a,b}, S. Braibant-Giacomelli^{a,b}, L. Brigliadori^{a,b}, R. Campanini^{a,b}, P. Capiluppi^{a,b}, A. Castro^{a,b}, F.R. Cavallo^a, G. Codispoti^{a,b}, M. Cuffiani^{a,b}, G.M. Dallavalle^a, F. Fabbri^a, A. Fanfani^{a,b}, D. Fasanella^{a,b}, P. Giacomelli^a, C. Grandi^a, L. Guiducci^{a,b}, S. Marcellini^a, G. Masetti^a, A. Montanari^a, F.L. Navarria^{a,b}, A. Perrotta^a, A.M. Rossi^{a,b}, T. Rovelli^{a,b}, G.P. Siroli^{a,b}, N. Tosi^{a,b}, R. Travaglini^{a,b}

^a INFN Sezione di Bologna, Bologna, Italy

^b Università di Bologna, Bologna, Italy

S. Albergo^{a,b}, G. Cappello^a, M. Chiorboli^{a,b}, S. Costa^{a,b}, F. Giordano^{a,2}, R. Potenza^{a,b}, A. Tricomi^{a,b}, C. Tuve^{a,b}

^a INFN Sezione di Catania, Catania, Italy

^b Università di Catania, Catania, Italy

^c CSFNSM, Catania, Italy

G. Barbagli ^a, V. Ciulli ^{a,b}, C. Civinini ^a, R. D'Alessandro ^{a,b}, E. Focardi ^{a,b}, E. Gallo ^a, S. Gonzi ^{a,b}, V. Gori ^{a,b}, P. Lenzi ^{a,b}, M. Meschini ^a, S. Paoletti ^a, G. Sguazzoni ^a, A. Tropiano ^{a,b}

^a INFN Sezione di Firenze, Firenze, Italy

^b Università di Firenze, Firenze, Italy

L. Benussi, S. Bianco, F. Fabbri, D. Piccolo

INFN Laboratori Nazionali di Frascati, Frascati, Italy

R. Ferretti ^{a,b}, F. Ferro ^a, M. Lo Vetere ^{a,b}, E. Robutti ^a, S. Tosi ^{a,b}

^a INFN Sezione di Genova, Genova, Italy

^b Università di Genova, Genova, Italy

M.E. Dinardo ^{a,b}, S. Fiorendi ^{a,b}, S. Gennai ^{a,2}, R. Gerosa ^{a,b,2}, A. Ghezzi ^{a,b}, P. Govoni ^{a,b}, M.T. Lucchini ^{a,b,2}, S. Malvezzi ^a, R.A. Manzoni ^{a,b}, A. Martelli ^{a,b}, B. Marzocchi ^{a,b,2}, D. Menasce ^a, L. Moroni ^a, M. Paganoni ^{a,b}, D. Pedrini ^a, S. Ragazzi ^{a,b}, N. Redaelli ^a, T. Tabarelli de Fatis ^{a,b}

^a INFN Sezione di Milano-Bicocca, Milano, Italy

^b Università di Milano-Bicocca, Milano, Italy

S. Buontempo ^a, N. Cavallo ^{a,c}, S. Di Guida ^{a,d,2}, F. Fabozzi ^{a,c}, A.O.M. Iorio ^{a,b}, L. Lista ^a, S. Meola ^{a,d,2}, M. Merola ^a, P. Paolucci ^{a,2}

^a INFN Sezione di Napoli, Napoli, Italy

^b Università di Napoli 'Federico II', Napoli, Italy

^c Università della Basilicata (Potenza), Napoli, Italy

^d Università G. Marconi (Roma), Napoli, Italy

P. Azzi ^a, N. Bacchetta ^a, D. Bisello ^{a,b}, R. Carlin ^{a,b}, P. Checchia ^a, M. Dall'Osso ^{a,b}, T. Dorigo ^a, F. Gasparini ^{a,b}, U. Gasparini ^{a,b}, A. Gozzelino ^a, M. Gulmini ^{a,25}, K. Kanishchev ^{a,c}, S. Lacaprara ^a, M. Margoni ^{a,b}, A.T. Meneguzzo ^{a,b}, M. Passaseo ^a, J. Pazzini ^{a,b}, N. Pozzobon ^{a,b}, P. Ronchese ^{a,b}, F. Simonetto ^{a,b}, E. Torassa ^a, M. Tosi ^{a,b}, P. Zotto ^{a,b}, A. Zucchetta ^{a,b}, G. Zumerle ^{a,b}

^a INFN Sezione di Padova, Padova, Italy

^b Università di Padova, Padova, Italy

^c Università di Trento (Trento), Padova, Italy

M. Gabusi ^{a,b}, S.P. Ratti ^{a,b}, V. Re ^a, C. Riccardi ^{a,b}, P. Salvini ^a, P. Vitulo ^{a,b}

^a INFN Sezione di Pavia, Pavia, Italy

^b Università di Pavia, Pavia, Italy

M. Biasini ^{a,b}, G.M. Bilei ^a, D. Ciangottini ^{a,b,2}, L. Fanò ^{a,b}, P. Lariccia ^{a,b}, G. Mantovani ^{a,b}, M. Menichelli ^a, A. Saha ^a, A. Santocchia ^{a,b}, A. Spiezia ^{a,b,2}

^a INFN Sezione di Perugia, Perugia, Italy

^b Università di Perugia, Perugia, Italy

K. Androsov ^{a,26}, P. Azzurri ^a, G. Bagliesi ^a, J. Bernardini ^a, T. Boccali ^a, G. Broccolo ^{a,c}, R. Castaldi ^a, M.A. Ciocci ^{a,26}, R. Dell'Orso ^a, S. Donato ^{a,c,2}, G. Fedi, F. Fiori ^{a,c}, L. Foà ^{a,c}, A. Giassi ^a, M.T. Grippo ^{a,26}, F. Ligabue ^{a,c}, T. Lomtadze ^a, L. Martini ^{a,b}, A. Messineo ^{a,b}, C.S. Moon ^{a,27}, F. Palla ^{a,2}, A. Rizzi ^{a,b}, A. Savoy-Navarro ^{a,28}, A.T. Serban ^a, P. Spagnolo ^a, P. Squillacioti ^{a,26}, R. Tenchini ^a, G. Tonelli ^{a,b}, A. Venturi ^a, P.G. Verdini ^a, C. Vernieri ^{a,c}

^a INFN Sezione di Pisa, Pisa, Italy

^b Università di Pisa, Pisa, Italy

^c Scuola Normale Superiore di Pisa, Pisa, Italy

L. Barone ^{a,b}, F. Cavallari ^a, G. D'imperio ^{a,b}, D. Del Re ^{a,b}, M. Diemoz ^a, C. Jorda ^a, E. Longo ^{a,b}, F. Margaroli ^{a,b}, P. Meridiani ^a, F. Micheli ^{a,b,2}, G. Organtini ^{a,b}, R. Paramatti ^a, S. Rahatlou ^{a,b}, C. Rovelli ^a, F. Santanastasio ^{a,b}, L. Soffi ^{a,b}, P. Traczyk ^{a,b,2}

^a INFN Sezione di Roma, Roma, Italy

^b Università di Roma, Roma, Italy

N. Amapane^{a,b}, R. Arcidiacono^{a,c}, S. Argiro^{a,b}, M. Arneodo^{a,c}, R. Bellan^{a,b}, C. Biino^a, N. Cartiglia^a, S. Casasso^{a,b,2}, M. Costa^{a,b}, R. Covarelli, A. Degano^{a,b}, N. Demaria^a, L. Finco^{a,b,2}, C. Mariotti^a, S. Maselli^a, E. Migliore^{a,b}, V. Monaco^{a,b}, M. Musich^a, M.M. Obertino^{a,c}, L. Pacher^{a,b}, N. Pastrone^a, M. Pelliccioni^a, G.L. Pinna Angioni^{a,b}, A. Potenza^{a,b}, A. Romero^{a,b}, M. Ruspa^{a,c}, R. Sacchi^{a,b}, A. Solano^{a,b}, A. Staiano^a, U. Tamponi^a

^a INFN Sezione di Torino, Torino, Italy

^b Università di Torino, Torino, Italy

^c Università del Piemonte Orientale (Novara), Torino, Italy

S. Belforte^a, V. Candelise^{a,b,2}, M. Casarsa^a, F. Cossutti^a, G. Della Ricca^{a,b}, B. Gobbo^a, C. La Licata^{a,b}, M. Marone^{a,b}, A. Schizzi^{a,b}, T. Umer^{a,b}, A. Zanetti^a

^a INFN Sezione di Trieste, Trieste, Italy

^b Università di Trieste, Trieste, Italy

S. Chang, A. Kropivnitskaya, S.K. Nam

Kangwon National University, Chunchon, Republic of Korea

D.H. Kim, G.N. Kim, M.S. Kim, D.J. Kong, S. Lee, Y.D. Oh, H. Park, A. Sakharov, D.C. Son

Kyungpook National University, Daegu, Republic of Korea

T.J. Kim, M.S. Ryu

Chonbuk National University, Jeonju, Republic of Korea

J.Y. Kim, D.H. Moon, S. Song

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Republic of Korea

S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, Y. Kim, B. Lee, K.S. Lee, S.K. Park, Y. Roh

Korea University, Seoul, Republic of Korea

H.D. Yoo

Seoul National University, Seoul, Republic of Korea

M. Choi, J.H. Kim, I.C. Park, G. Ryu

University of Seoul, Seoul, Republic of Korea

Y. Choi, Y.K. Choi, J. Goh, D. Kim, E. Kwon, J. Lee, I. Yu

Sungkyunkwan University, Suwon, Republic of Korea

A. Juodagalvis

Vilnius University, Vilnius, Lithuania

J.R. Komaragiri, M.A.B. Md Ali, W.A.T. Wan Abdullah

National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia

E. Casimiro Linares, H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz, A. Hernandez-Almada, R. Lopez-Fernandez, A. Sanchez-Hernandez

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Universidad Iberoamericana, Mexico City, Mexico

I. Pedraza, H.A. Salazar Ibarguen

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

A. Morelos Pineda*Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico***D. Krofcheck***University of Auckland, Auckland, New Zealand***P.H. Butler, S. Reucroft***University of Canterbury, Christchurch, New Zealand***A. Ahmad, M. Ahmad, Q. Hassan, H.R. Hoorani, W.A. Khan, T. Khurshid, M. Shoaib***National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan***H. Bialkowska, M. Bluj, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, P. Zalewski***National Centre for Nuclear Research, Swierk, Poland***G. Brona, K. Bunkowski, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski***Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland***P. Bargassa, C. Beirão Da Cruz E Silva, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, L. Lloret Iglesias, F. Nguyen, J. Rodrigues Antunes, J. Seixas, J. Varela, P. Vischia***Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal***M. Gavrilenko, I. Golutvin, A. Kamenev, V. Karjavin, V. Konoplyanikov, V. Korenkov, G. Kozlov, A. Lanev, A. Malakhov, V. Matveev²⁹, V.V. Mitsyn, P. Moisezenz, V. Palichik, V. Perelygin, S. Shmatov, V. Smirnov, E. Tikhonenko, A. Zarubin***Joint Institute for Nuclear Research, Dubna, Russia***V. Golovtsov, Y. Ivanov, V. Kim³⁰, E. Kuznetsova, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev, An. Vorobyev***Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia***Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, M. Kirsanov, N. Krasnikov, A. Pashenkov, D. Tilsov, A. Toropin***Institute for Nuclear Research, Moscow, Russia***V. Epshteyn, V. Gavrilo, N. Lychkovskaya, V. Popov, I. Pozdnyakov, G. Safronov, S. Semenov, A. Spiridonov, V. Stolin, E. Vlasov, A. Zhokin***Institute for Theoretical and Experimental Physics, Moscow, Russia***V. Andreev, M. Azarkin³¹, I. Dremin³¹, M. Kirakosyan, A. Leonidov³¹, G. Mesyats, S.V. Rusakov, A. Vinogradov***P.N. Lebedev Physical Institute, Moscow, Russia***A. Belyaev, E. Boos, M. Dubinin³², L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev***Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia***I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, A. Kalinin, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov***State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia*

P. Adzic³³, M. Ekmedzic, J. Milosevic, V. Rekovic

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia

J. Alcaraz Maestre, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, A. Escalante Del Valle, C. Fernandez Bedoya, J.P. Fernández Ramos, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, E. Navarro De Martino, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, M.S. Soares

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain

C. Albajar, J.F. de Trocóniz, M. Missiroli, D. Moran

Universidad Autónoma de Madrid, Madrid, Spain

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero

Universidad de Oviedo, Oviedo, Spain

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, J. Duarte Campderros, M. Fernandez, G. Gomez, A. Graziano, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, J. Piedra Gomez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, A. Benaglia, J. Bendavid, L. Benhabib, J.F. Benitez, P. Bloch, A. Bocci, A. Bonato, O. Bondu, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, S. Colafranceschi³⁴, M. D'Alfonso, D. d'Enterria, A. Dabrowski, A. David, F. De Guio, A. De Roeck, S. De Visscher, E. Di Marco, M. Dobson, M. Dordevic, B. Dorney, N. Dupont-Sagorin, A. Elliott-Peisert, G. Franzoni, W. Funk, D. Gigi, K. Gill, D. Giordano, M. Girone, F. Glege, R. Guida, S. Gundacker, M. Guthoff, J. Hammer, M. Hansen, P. Harris, J. Hegeman, V. Innocente, P. Janot, K. Kousouris, K. Krajczar, P. Lecoq, C. Lourenço, N. Magini, L. Malgeri, M. Mannelli, J. Marrouche, L. Masetti, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, S. Morovic, M. Mulders, L. Orsini, L. Pape, E. Perez, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pimiä, D. Piparo, M. Plagge, A. Racz, G. Rolandi³⁵, M. Rovere, H. Sakulin, C. Schäfer, C. Schwick, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas³⁶, D. Spiga, J. Steggemann, B. Stieger, M. Stoye, Y. Takahashi, D. Treille, A. Tsiros, G.I. Veres¹⁷, N. Wardle, H.K. Wöhri, H. Wollny, W.D. Zeuner

CERN, European Organization for Nuclear Research, Geneva, Switzerland

W. Bertl, K. Deiters, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, D. Kotlinski, U. Langenegger, D. Renker, T. Rohe

Paul Scherrer Institut, Villigen, Switzerland

F. Bachmair, L. Bäni, L. Bianchini, M.A. Buchmann, B. Casal, N. Chanon, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, C. Grab, D. Hits, J. Hoss, G. Kasieczka, W. Lustermann, B. Mangano, A.C. Marini, M. Marionneau, P. Martinez Ruiz del Arbol, M. Masciovecchio, D. Meister, N. Mohr, P. Musella, C. Nägeli³⁷, F. Nessi-Tedaldi, F. Pandolfi, F. Pauss, L. Perrozzi, M. Peruzzi, M. Quittnat, L. Rebane, M. Rossini, A. Starodumov³⁸, M. Takahashi, K. Theofilatos, R. Wallny, H.A. Weber

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

C. Amsler³⁹, M.F. Canelli, V. Chiochia, A. De Cosa, A. Hinzmann, T. Hreus, B. Kilminster, C. Lange, J. Ngadiuba, D. Pinna, P. Robmann, F.J. Ronga, S. Taroni, Y. Yang

Universität Zürich, Zurich, Switzerland

M. Cardaci, K.H. Chen, C. Ferro, C.M. Kuo, W. Lin, Y.J. Lu, R. Volpe, S.S. Yu

National Central University, Chung-Li, Taiwan

P. Chang, Y.H. Chang, Y. Chao, K.F. Chen, P.H. Chen, C. Dietz, U. Grundler, W.-S. Hou, Y.F. Liu, R.-S. Lu, M. Miñano Moya, E. Petrakou, Y.M. Tzeng, R. Wilken

National Taiwan University (NTU), Taipei, Taiwan

B. Asavapibhop, G. Singh, N. Srimanobhas, N. Suwonjandee

Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand

A. Adiguzel, M.N. Bakirci⁴⁰, S. Cerci⁴¹, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos, E.E. Kangal⁴², A. Kayis Topaksu, G. Onengut⁴³, K. Ozdemir⁴⁴, S. Ozturk⁴⁰, A. Polatoz, D. Sunar Cerci⁴¹, B. Tali⁴¹, H. Topakli⁴⁰, M. Vergili, C. Zorbilmez

Cukurova University, Adana, Turkey

I.V. Akin, B. Bilin, S. Bilmis, H. Gamsizkan⁴⁵, B. Isildak⁴⁶, G. Karapinar⁴⁷, K. Ocalan⁴⁸, S. Sekmen, U.E. Surat, M. Yalvac, M. Zeyrek

Middle East Technical University, Physics Department, Ankara, Turkey

E.A. Albayrak⁴⁹, E. Gülmez, M. Kaya⁵⁰, O. Kaya⁵¹, T. Yetkin⁵²

Bogazici University, Istanbul, Turkey

K. Cankocak, F.I. Vardarli

Istanbul Technical University, Istanbul, Turkey

L. Levchuk, P. Sorokin

National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine

J.J. Brooke, E. Clement, D. Cussans, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, Z. Meng, D.M. Newbold⁵³, S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, S. Senkin, V.J. Smith

University of Bristol, Bristol, United Kingdom

K.W. Bell, A. Belyaev⁵⁴, C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, T. Williams, W.J. Womersley, S.D. Worm

Rutherford Appleton Laboratory, Didcot, United Kingdom

M. Baber, R. Bainbridge, O. Buchmuller, D. Burton, D. Colling, N. Cripps, P. Dauncey, G. Davies, M. Della Negra, P. Dunne, A. Elwood, W. Ferguson, J. Fulcher, D. Futyan, G. Hall, G. Iles, M. Jarvis, G. Karapostoli, M. Kenzie, R. Lane, R. Lucas⁵³, L. Lyons, A.-M. Magnan, S. Malik, B. Mathias, J. Nash, A. Nikitenko³⁸, J. Pela, M. Pesaresi, K. Petridis, D.M. Raymond, S. Rogerson, A. Rose, C. Seez, P. Sharp[†], A. Tapper, M. Vazquez Acosta, T. Virdee, S.C. Zenz

Imperial College, London, United Kingdom

J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leggat, D. Leslie, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

Brunel University, Uxbridge, United Kingdom

J. Dittmann, K. Hatakeyama, A. Kasmi, H. Liu, N. Pastika, T. Scarborough, Z. Wu

Baylor University, Waco, USA

O. Charaf, S.I. Cooper, C. Henderson, P. Rumerio

The University of Alabama, Tuscaloosa, USA

A. Avetisyan, T. Bose, C. Fantasia, P. Lawson, C. Richardson, J. Rohlf, J. St. John, L. Sulak

Boston University, Boston, USA

J. Alimena, E. Berry, S. Bhattacharya, G. Christopher, D. Cutts, Z. Demiragli, N. Dhingra, A. Ferapontov, A. Garabedian, U. Heintz, E. Laird, G. Landsberg, Z. Mao, M. Narain, S. Sagir, T. Sinthuprasith, T. Speer, J. Swanson

Brown University, Providence, USA

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, M. Gardner, W. Ko, R. Lander, M. Mulhearn, D. Pellett, J. Pilot, F. Ricci-Tam, S. Shalhout, J. Smith, M. Squires, D. Stolp, M. Tripathi, S. Wilbur, R. Yohay

University of California, Davis, Davis, USA

R. Cousins, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, G. Rakness, E. Takasugi, V. Valuev, M. Weber

University of California, Los Angeles, USA

K. Burt, R. Clare, J. Ellison, J.W. Gary, G. Hanson, J. Heilman, M. Ivova Rikova, P. Jandir, E. Kennedy, F. Lacroix, O.R. Long, A. Luthra, M. Malberti, M. Olmedo Negrete, A. Shrinivas, S. Sumowidagdo, S. Wimpenny

University of California, Riverside, Riverside, USA

J.G. Branson, G.B. Cerati, S. Cittolin, R.T. D'Agnolo, A. Holzner, R. Kelley, D. Klein, J. Letts, I. Macneill, D. Olivito, S. Padhi, C. Palmer, M. Pieri, M. Sani, V. Sharma, S. Simon, M. Tadel, Y. Tu, A. Vartak, C. Welke, F. Würthwein, A. Yagil, G. Zevi Della Porta

University of California, San Diego, La Jolla, USA

D. Barge, J. Bradmiller-Feld, C. Campagnari, T. Danielson, A. Dishaw, V. Dutta, K. Flowers, M. Franco Sevilla, P. Geffert, C. George, F. Golf, L. Gouskos, J. Incandela, C. Justus, N. Mccoll, S.D. Mullin, J. Richman, D. Stuart, W. To, C. West, J. Yoo

University of California, Santa Barbara, Santa Barbara, USA

A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, J. Duarte, A. Mott, H.B. Newman, C. Pena, M. Pierini, M. Spiropulu, J.R. Vlimant, R. Wilkinson, S. Xie, R.Y. Zhu

California Institute of Technology, Pasadena, USA

V. Azzolini, A. Calamba, B. Carlson, T. Ferguson, Y. Iiyama, M. Paulini, J. Russ, H. Vogel, I. Vorobiev

Carnegie Mellon University, Pittsburgh, USA

J.P. Cumalat, W.T. Ford, A. Gaz, M. Krohn, E. Luigi Lopez, U. Nauenberg, J.G. Smith, K. Stenson, S.R. Wagner

University of Colorado at Boulder, Boulder, USA

J. Alexander, A. Chatterjee, J. Chaves, J. Chu, S. Dittmer, N. Eggert, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Ryd, E. Salvati, L. Skinnari, W. Sun, W.D. Teo, J. Thom, J. Thompson, J. Tucker, Y. Weng, L. Winstrom, P. Wittich

Cornell University, Ithaca, USA

D. Winn

Fairfield University, Fairfield, USA

S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, G. Bolla, K. Burkett, J.N. Butler, H.W.K. Cheung, F. Chlebana, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, J. Hanlon, D. Hare, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Klima, B. Kreis, S. Kwan[†], J. Linacre, D. Lincoln, R. Lipton, T. Liu, R. Lopes De Sá, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, P. Merkel, K. Mishra, S. Mrenna, S. Nahn, C. Newman-Holmes, V. O'Dell, O. Prokofyev, E. Sexton-Kennedy, A. Soha, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, A. Whitbeck, J. Whitmore, F. Yang

Fermi National Accelerator Laboratory, Batavia, USA

D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, M. Carver, D. Curry, S. Das, M. De Gruttola, G.P. Di Giovanni, R.D. Field, M. Fisher, I.K. Furic, J. Hugon, J. Konigsberg, A. Korytov, T. Kypreos, J.F. Low, K. Matchev, H. Mei, P. Milenovic⁵⁵, G. Mitselmakher, L. Muniz, A. Rinkevicius, L. Shchutska, M. Snowball, D. Sperka, J. Yelton, M. Zakaria

University of Florida, Gainesville, USA

S. Hewamanage, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida International University, Miami, USA

J.R. Adams, T. Adams, A. Askew, J. Bochenek, B. Diamond, J. Haas, S. Hagopian, V. Hagopian, K.F. Johnson, H. Prosper, V. Veeraraghavan, M. Weinberg

Florida State University, Tallahassee, USA

M.M. Baarmand, M. Hohlmann, H. Kalakhety, F. Yumiceva

Florida Institute of Technology, Melbourne, USA

M.R. Adams, L. Apanasevich, D. Berry, R.R. Betts, I. Bucinskaite, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, P. Kurt, C. O'Brien, I.D. Sandoval Gonzalez, C. Silkworth, P. Turner, N. Varelas

University of Illinois at Chicago (UIC), Chicago, USA

B. Bilki⁵⁶, W. Clarida, K. Dilsiz, M. Haytmyradov, J.-P. Merlo, H. Mermerkaya⁵⁷, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok⁴⁹, A. Penzo, R. Rahmat, S. Sen, P. Tan, E. Tiras, J. Wetzel, K. Yi

The University of Iowa, Iowa City, USA

I. Anderson, B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, A.V. Gritsan, P. Maksimovic, C. Martin, M. Swartz, M. Xiao

Johns Hopkins University, Baltimore, USA

P. Baringer, A. Bean, G. Benelli, C. Bruner, J. Gray, R.P. Kenny III, D. Majumder, M. Malek, M. Murray, D. Noonan, S. Sanders, J. Sekaric, R. Stringer, Q. Wang, J.S. Wood

The University of Kansas, Lawrence, USA

I. Chakaberia, A. Ivanov, K. Kaadze, S. Khalil, M. Makouski, Y. Maravin, L.K. Saini, N. Skhirtladze, I. Svintradze

Kansas State University, Manhattan, USA

J. Gronberg, D. Lange, F. Rebassoo, D. Wright

Lawrence Livermore National Laboratory, Livermore, USA

A. Baden, A. Belloni, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, S. Jabeen, R.G. Kellogg, T. Kolberg, Y. Lu, A.C. Mignerey, K. Pedro, A. Skuja, M.B. Tonjes, S.C. Tonwar

University of Maryland, College Park, USA

A. Apyan, R. Barbieri, K. Bierwagen, W. Busza, I.A. Cali, L. Di Matteo, G. Gomez Ceballos, M. Goncharov, D. Gulhan, M. Klute, Y.S. Lai, Y.-J. Lee, A. Levin, P.D. Luckey, C. Paus, D. Ralph, C. Roland, G. Roland, G.S.F. Stephans, K. Sumorok, D. Velicanu, J. Veverka, B. Wyslouch, M. Yang, M. Zanetti, V. Zhukova

Massachusetts Institute of Technology, Cambridge, USA

B. Dahmes, A. Gude, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, S. Nourbakhsh, R. Rusack, A. Singovsky, N. Tambe, J. Turkewitz

University of Minnesota, Minneapolis, USA

J.G. Acosta, S. Oliveros

University of Mississippi, Oxford, USA

E. Avdeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, R. Gonzalez Suarez, J. Keller, D. Knowlton, I. Kravchenko, J. Lazo-Flores, F. Meier, F. Ratnikov, G.R. Snow, M. Zvada

University of Nebraska-Lincoln, Lincoln, USA

J. Dolen, A. Godshalk, I. Iashvili, A. Kharchilava, A. Kumar, S. Rappoccio

State University of New York at Buffalo, Buffalo, USA

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, A. Massironi, D.M. Morse, D. Nash, T. Orimoto, D. Trocino, R.-J. Wang, D. Wood, J. Zhang

Northeastern University, Boston, USA

K.A. Hahn, A. Kubik, N. Mucia, N. Odell, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, K. Sung, M. Velasco, S. Won

Northwestern University, Evanston, USA

A. Brinkerhoff, K.M. Chan, A. Drozdetskiy, M. Hildreth, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, S. Lynch, N. Marinelli, Y. Musienko²⁹, T. Pearson, M. Planer, R. Ruchti, G. Smith, N. Valls, M. Wayne, M. Wolf, A. Woodard

University of Notre Dame, Notre Dame, USA

L. Antonelli, J. Brinson, B. Bylsma, L.S. Durkin, S. Flowers, A. Hart, C. Hill, R. Hughes, K. Kotov, T.Y. Ling, W. Luo, D. Puigh, M. Rodenburg, B.L. Winer, H. Wolfe, H.W. Wulsin

The Ohio State University, Columbus, USA

O. Driga, P. Elmer, J. Hardenbrook, P. Hebda, S.A. Koay, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, H. Saka, D. Stickland², C. Tully, J.S. Werner, A. Zuranski

Princeton University, Princeton, USA

E. Brownson, S. Malik, H. Mendez, J.E. Ramirez Vargas

University of Puerto Rico, Mayaguez, USA

V.E. Barnes, D. Benedetti, D. Bortoletto, M. De Mattia, L. Gutay, Z. Hu, M.K. Jha, M. Jones, K. Jung, M. Kress, N. Leonardo, D.H. Miller, N. Neumeister, F. Primavera, B.C. Radburn-Smith, X. Shi, I. Shipsey, D. Silvers, A. Svyatkovskiy, F. Wang, W. Xie, L. Xu, J. Zablocki

Purdue University, West Lafayette, USA

N. Parashar, J. Stupak

Purdue University Calumet, Hammond, USA

A. Adair, B. Akgun, K.M. Ecklund, F.J.M. Geurts, W. Li, B. Michlin, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

Rice University, Houston, USA

B. Betchart, A. Bodek, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, M. Galanti, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, O. Hindrichs, A. Khukhunaishvili, S. Korjenevski, G. Petrillo, M. Verzetti, D. Vishnevskiy

University of Rochester, Rochester, USA

R. Ciesielski, L. Demortier, K. Goulianos, C. Mesropian

The Rockefeller University, New York, USA

S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, S. Kaplan, A. Lath, S. Panwalkar, M. Park, S. Salur, S. Schnetzer, D. Sheffield, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

Rutgers, The State University of New Jersey, Piscataway, USA

K. Rose, S. Spanier, A. York

University of Tennessee, Knoxville, USA

O. Bouhali⁵⁸, A. Castaneda Hernandez, S. Dildick, R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon⁵⁹, V. Khotilovich, V. Krutelyov, R. Montalvo, I. Osipenkov, Y. Pakhotin, R. Patel, A. Perloff, J. Roe, A. Rose, A. Safonov, I. Suarez, A. Tatarinov, K.A. Ulmer

Texas A&M University, College Station, USA

N. Akchurin, C. Cowden, J. Damgov, C. Dragoiu, P.R. Duder, J. Faulkner, K. Kovitanggoon, S. Kunori, S.W. Lee, T. Libeiro, I. Volobouev

Texas Tech University, Lubbock, USA

E. Appelt, A.G. Delannoy, S. Greene, A. Gurrola, W. Johns, C. Maguire, Y. Mao, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

Vanderbilt University, Nashville, USA

M.W. Arenton, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, H. Li, C. Lin, C. Neu, E. Wolfe, J. Wood

University of Virginia, Charlottesville, USA

C. Clarke, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, J. Sturdy

Wayne State University, Detroit, USA

D.A. Belknap, D. Carlsmith, M. Cepeda, S. Dasu, L. Dodd, S. Duric, E. Friis, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, A. Lanaro, C. Lazaridis, A. Levine, R. Loveless, A. Mohapatra, I. Ojalvo, T. Perry, G.A. Pierro, G. Polese, I. Ross, T. Sarangi, A. Savin, W.H. Smith, D. Taylor, C. Vuosalo, N. Woods

University of Wisconsin, Madison, USA

E-mail address: cms-publication-committee-chair@cern.ch (G. Hamel de Monchenault).

[†] Deceased.

¹ Also at Vienna University of Technology, Vienna, Austria.

² Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.

- ³ Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France.
- ⁴ Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia.
- ⁵ Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.
- ⁶ Also at Universidade Estadual de Campinas, Campinas, Brazil.
- ⁷ Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France.
- ⁸ Also at Joint Institute for Nuclear Research, Dubna, Russia.
- ⁹ Also at Suez University, Suez, Egypt.
- ¹⁰ Also at Cairo University, Cairo, Egypt.
- ¹¹ Also at Fayoum University, El-Fayoum, Egypt.
- ¹² Also at British University in Egypt, Cairo, Egypt.
- ¹³ Now at Ain Shams University, Cairo, Egypt.
- ¹⁴ Also at Université de Haute Alsace, Mulhouse, France.
- ¹⁵ Also at Brandenburg University of Technology, Cottbus, Germany.
- ¹⁶ Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
- ¹⁷ Also at Eötvös Loránd University, Budapest, Hungary.
- ¹⁸ Also at University of Debrecen, Debrecen, Hungary.
- ¹⁹ Also at University of Visva-Bharati, Santiniketan, India.
- ²⁰ Now at King Abdulaziz University, Jeddah, Saudi Arabia.
- ²¹ Also at University of Ruhuna, Matara, Sri Lanka.
- ²² Also at Isfahan University of Technology, Isfahan, Iran.
- ²³ Also at University of Tehran, Department of Engineering Science, Tehran, Iran.
- ²⁴ Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.
- ²⁵ Also at Laboratori Nazionali di Legnaro dell'INFN, Legnaro, Italy.
- ²⁶ Also at Università degli Studi di Siena, Siena, Italy.
- ²⁷ Also at Centre National de la Recherche Scientifique (CNRS) – IN2P3, Paris, France.
- ²⁸ Also at Purdue University, West Lafayette, USA.
- ²⁹ Also at Institute for Nuclear Research, Moscow, Russia.
- ³⁰ Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.
- ³¹ Also at National Research Nuclear University "Moscow Engineering Physics Institute" (MEPhI), Moscow, Russia.
- ³² Also at California Institute of Technology, Pasadena, USA.
- ³³ Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
- ³⁴ Also at Facoltà Ingegneria, Università di Roma, Roma, Italy.
- ³⁵ Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.
- ³⁶ Also at University of Athens, Athens, Greece.
- ³⁷ Also at Paul Scherrer Institut, Villigen, Switzerland.
- ³⁸ Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
- ³⁹ Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland.
- ⁴⁰ Also at Gaziosmanpasa University, Tokat, Turkey.
- ⁴¹ Also at Adiyaman University, Adiyaman, Turkey.
- ⁴² Also at Mersin University, Mersin, Turkey.
- ⁴³ Also at Cag University, Mersin, Turkey.
- ⁴⁴ Also at Piri Reis University, Istanbul, Turkey.
- ⁴⁵ Also at Anadolu University, Eskisehir, Turkey.
- ⁴⁶ Also at Ozyegin University, Istanbul, Turkey.
- ⁴⁷ Also at Izmir Institute of Technology, Izmir, Turkey.
- ⁴⁸ Also at Necmettin Erbakan University, Konya, Turkey.
- ⁴⁹ Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
- ⁵⁰ Also at Marmara University, Istanbul, Turkey.
- ⁵¹ Also at Kafkas University, Kars, Turkey.
- ⁵² Also at Yildiz Technical University, Istanbul, Turkey.
- ⁵³ Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
- ⁵⁴ Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- ⁵⁵ Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
- ⁵⁶ Also at Argonne National Laboratory, Argonne, USA.
- ⁵⁷ Also at Erzincan University, Erzincan, Turkey.
- ⁵⁸ Also at Texas A&M University at Qatar, Doha, Qatar.
- ⁵⁹ Also at Kyungpook National University, Daegu, Korea.